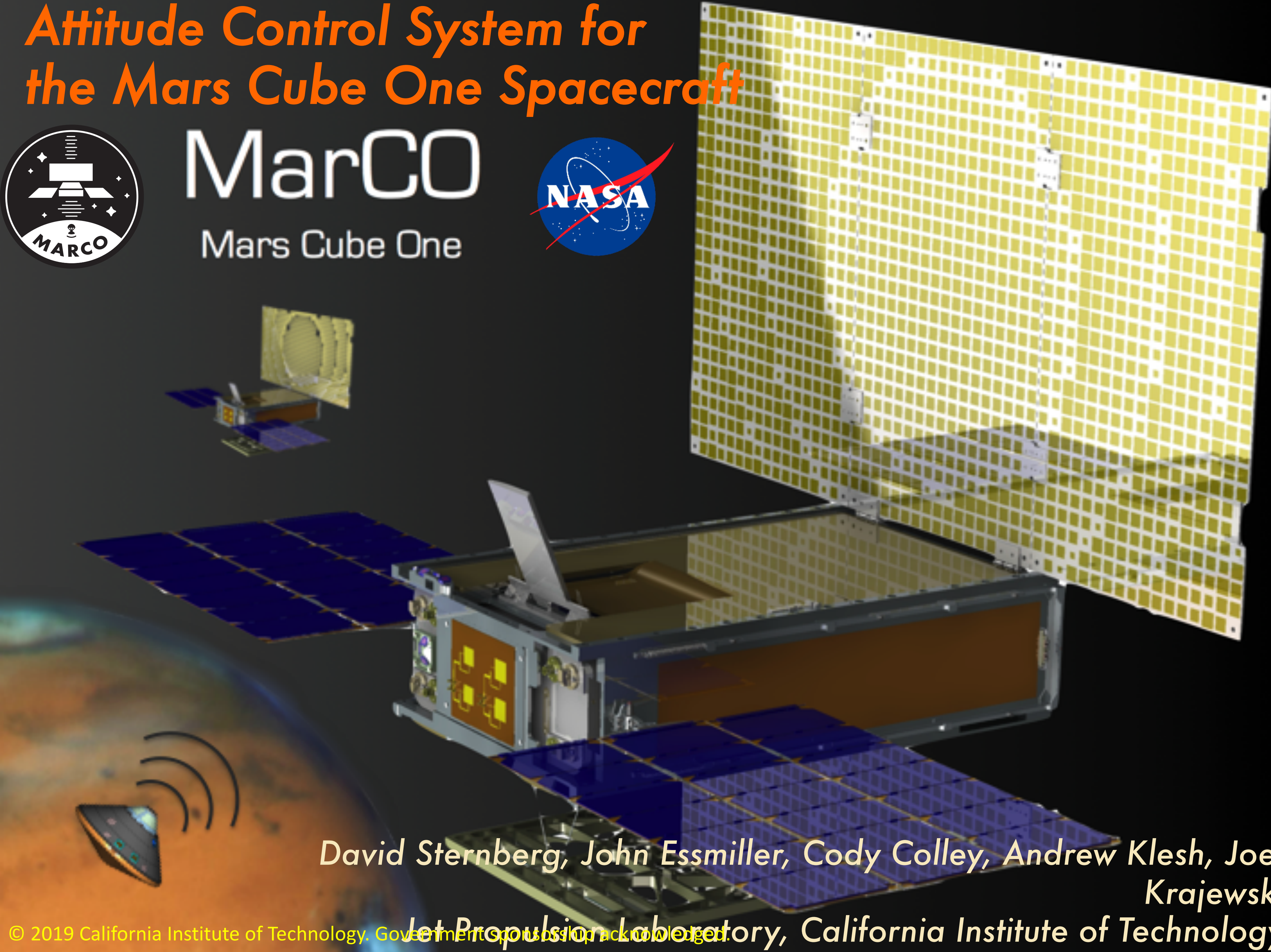
Attitude Control System for the Mars Cube One Spacecraft

MarCO

Mars Cube One



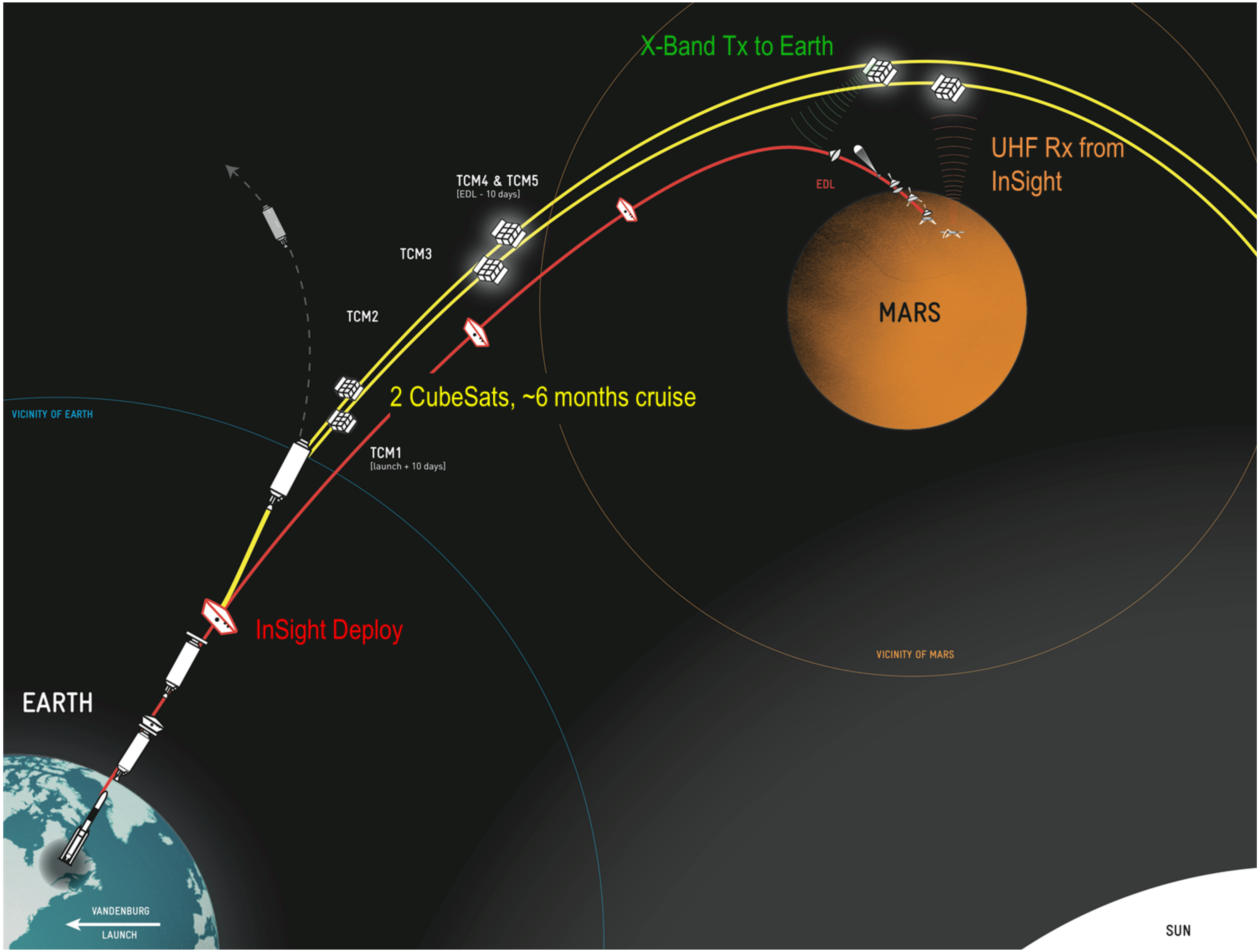
David Sternberg, John Essmiller, Cody Colley, Andrew Klesh, Joel Krajewski

Jet Propulsion Laboratory, California Institute of Technology

Outline

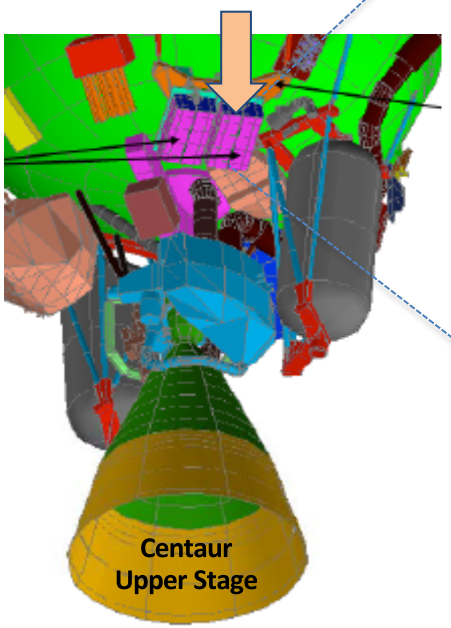
- MarCO Mission Summary
- Spacecraft Overview
- Attitude Control System Design
- Propulsion System Design
- Ground Testbed Overview
- Test Data
  - Sun pointing
  - Tipoff control
- Flight Data
  - Initial contact
  - Trajectory correction maneuver

MarCO Mission Summary



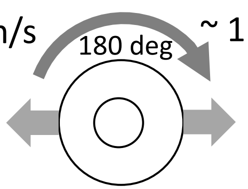
MarCO Mission Summary

1) *Deploy MarCO-A & -B*
from Tyvak Dispensers
(Twins for redundancy)

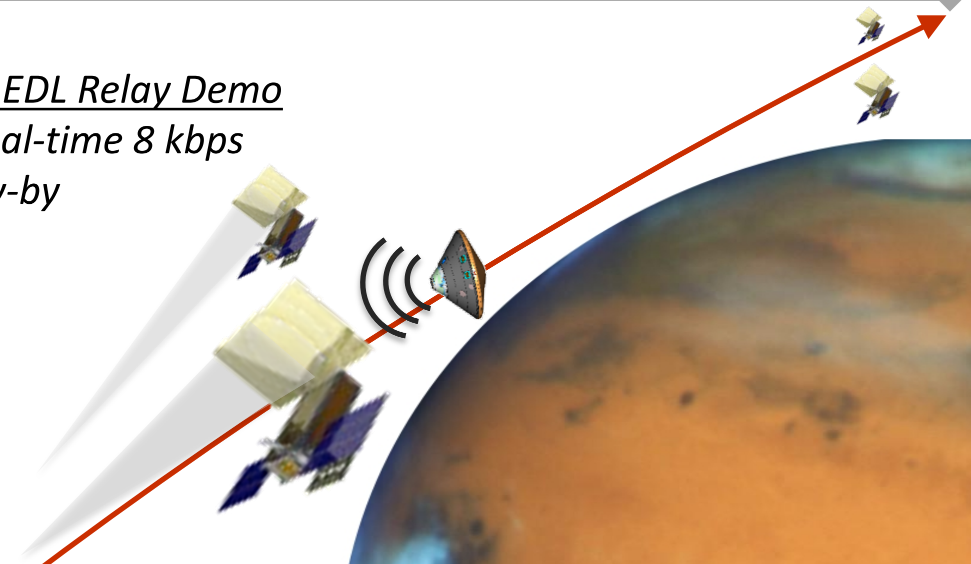


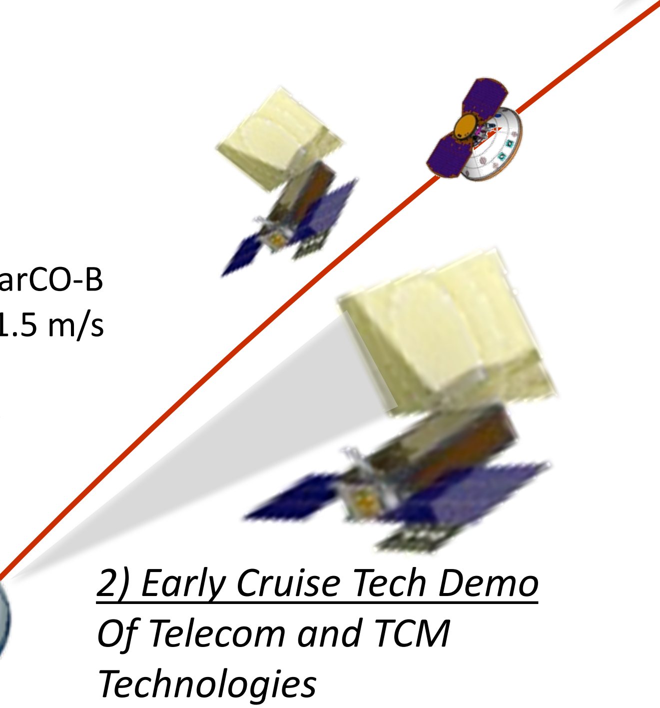
MarCO-A
~ 1.5 m/s

MarCO-B
~ 1.5 m/s



3) EDL Relay Demo
Real-time 8 kbps
Fly-by

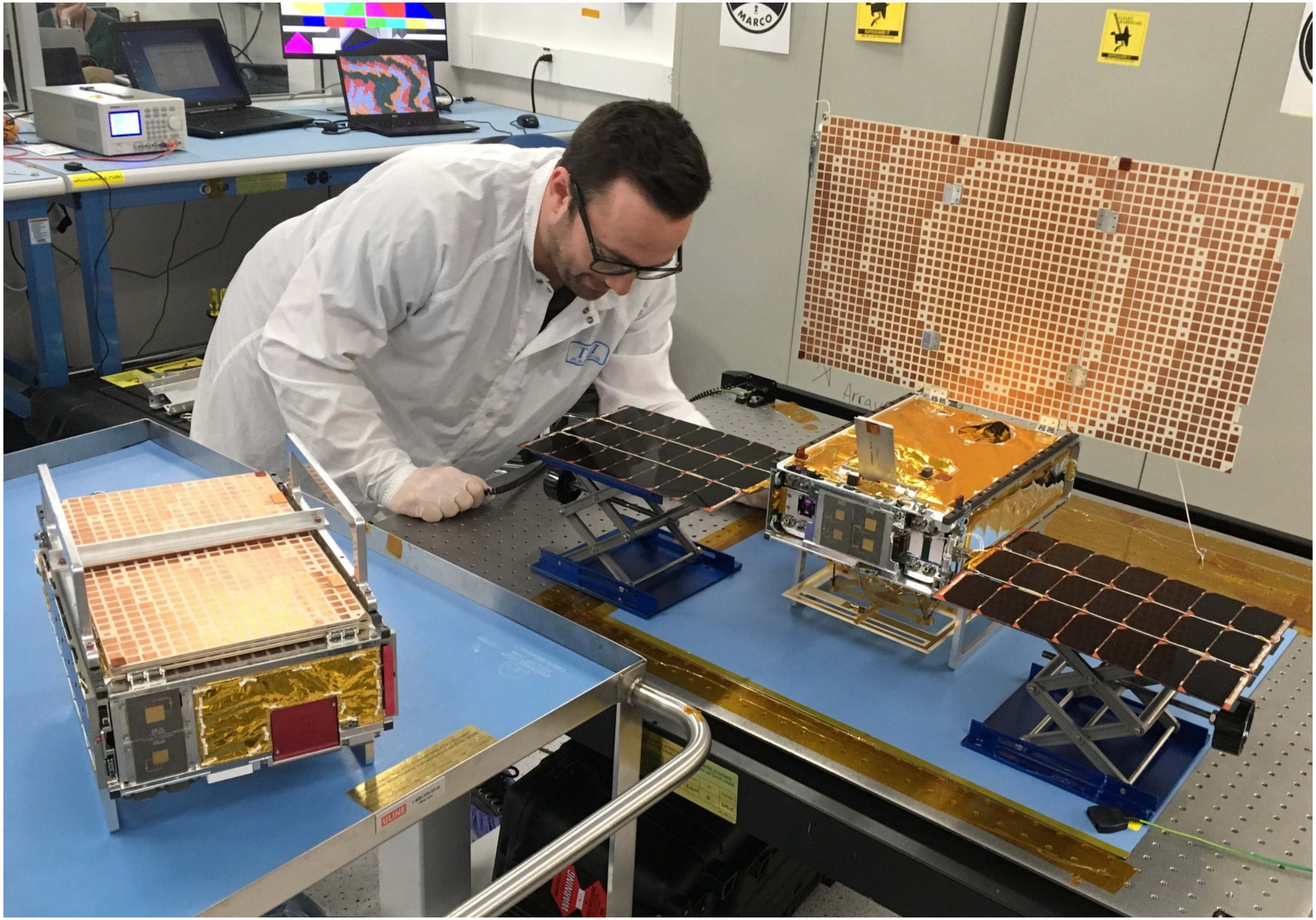




2) Early Cruise Tech Demo
Of Telecom and TCM
Technologies

Technology	Mission Objectives
Threshold	
Miniaturized deep space radio (IRIS)	Successful uplink and downlink at multiple data rates + ranging
Flat Panel Antenna	Receipt of telemetry at 8kbps
TCMs on a Cubesat	Execution of TCM 1
Baseline	
Cubesat in deep space	Viable operations beyond Earth orbit
Relay	Bent-pipe during Insight EDL

MarCO Spacecraft



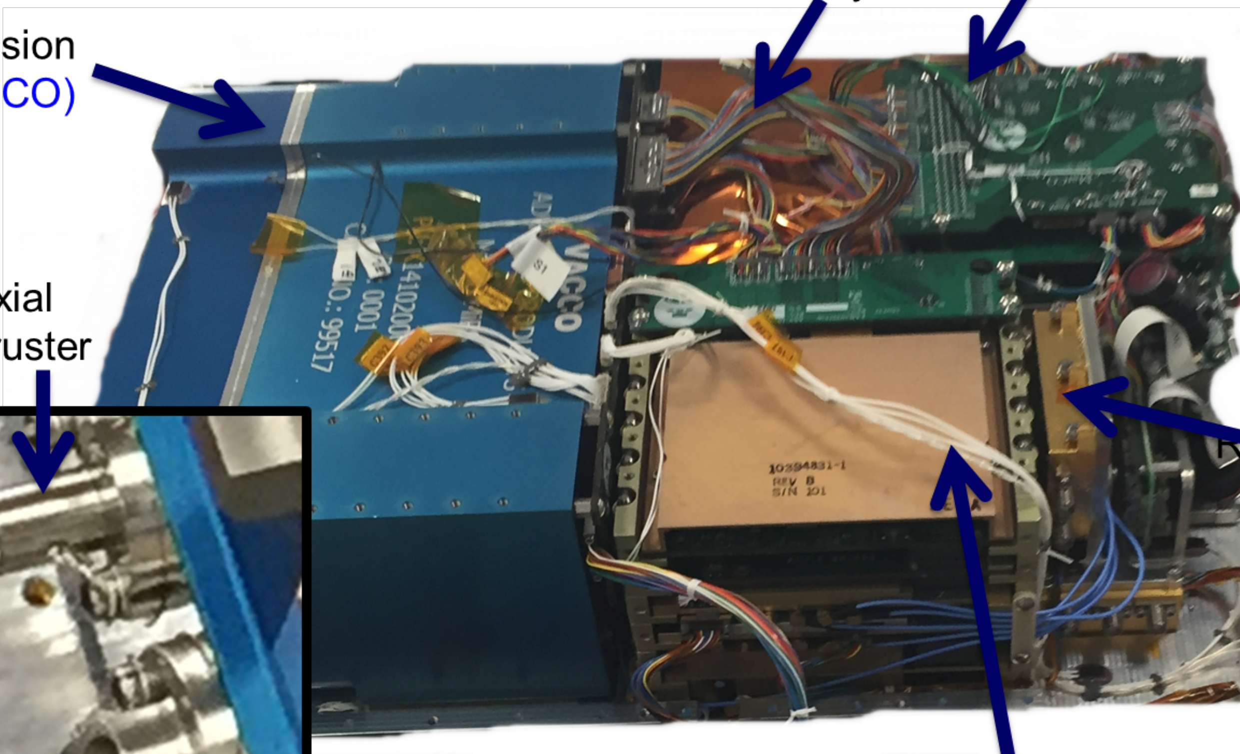
MarCO Internal Components Overview

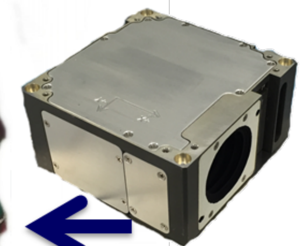
Battery

Avionics (Astrodev)

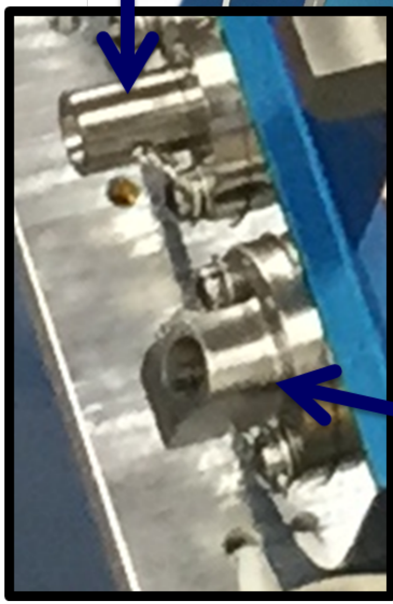
XACT ACS (BCT)

Propulsion (VACCO)





Axial Thruster

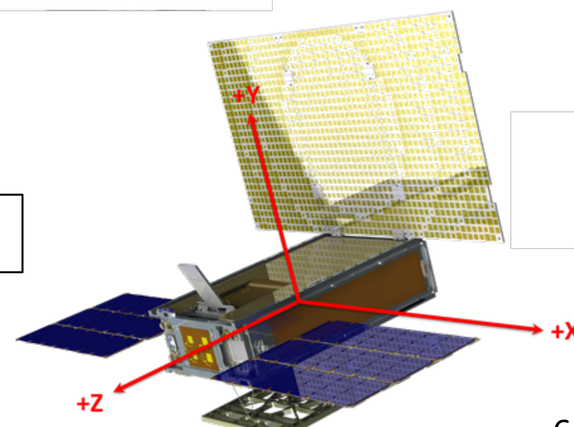


RF Amplifiers

Canted Thruster

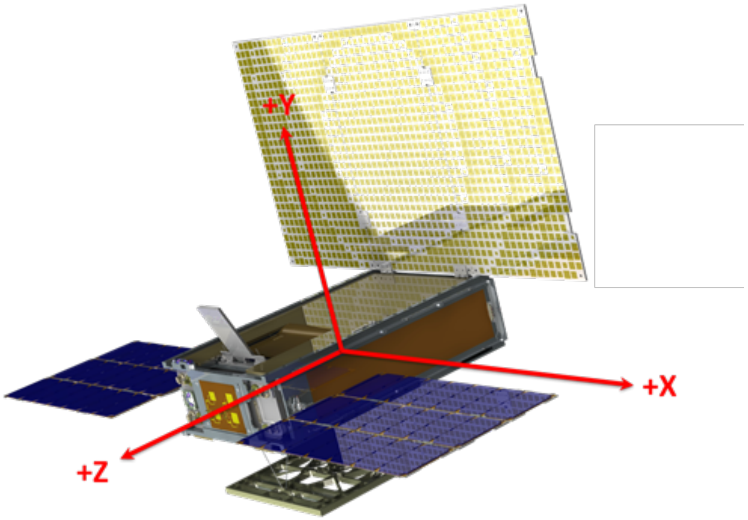
IRIS Radio (JPL)

Not shown: two coarse sun sensors



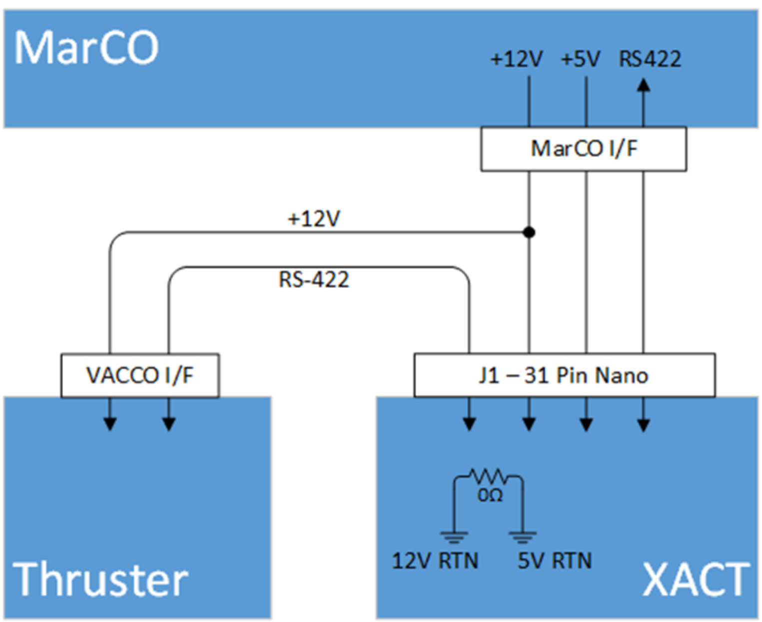
Key MarCO Body Vectors

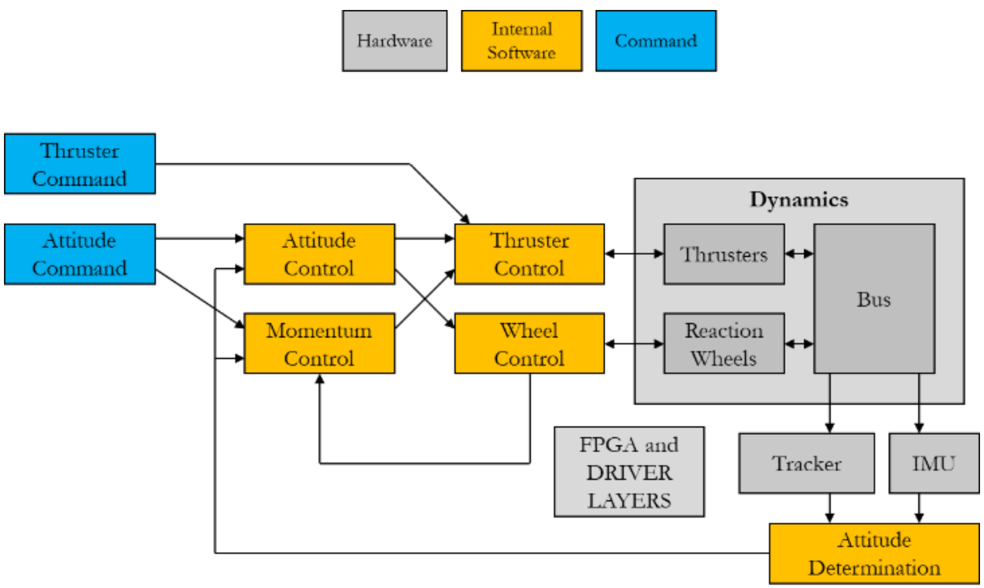
Name	Vector	Use
TCM Delta-V Thrust Direction	[0, 0, -1]	Trajectory correction
Radiator Normal	[0, -1, 0]	Thermal management
Star Tracker Boresight	[0, sin(10°), -cos(10°)]	Attitude determination, 10°x12° FOV, 1024x1280 px
Solar Array Normal	[0, 1, 0]	Power generation, thermal management
High Gain Antenna Boresight	[0, sin(22.7°), cos(22.7°)]	High-rate communications with the DSN
Medium Gain Antenna Boresight	[0, sin(22.7°), cos(22.7°)]	Medium-rate communications with the DSN
Low Gain Antenna Boresight	[0, 0, -1]	Low-rate communications with the DSN
UHF Antenna Boresight	[0, -1, 0]	UHF relay
Narrow Angle Camera Boresight	[0, -1, 0]	Public relations, 3.4° half-angle FOV
Wide Angle Camera Boresight	[0, sin(62°), cos(62°)]	HGA deployment verification, 77° half-angle FOV



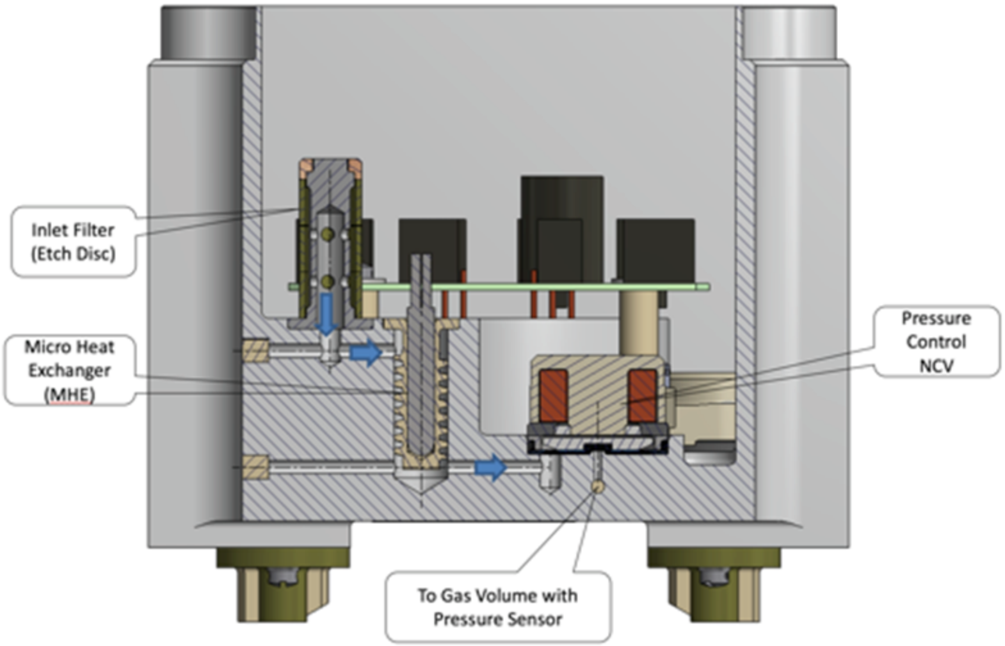
ACS/Prop Interface and Interaction

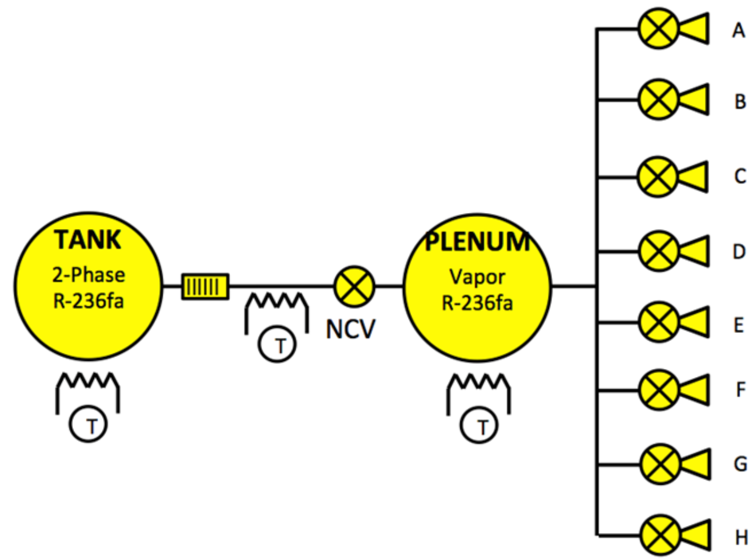
- All commands to propulsion system pass through the XACT
  - Ground commands for XACT's autonomous management of thrusters or for direct thruster actuation
  - Onboard ACS Manager (ACSM) prevents multiple ACS commands from being sent at once and reduces complexity of larger command sequences by acting on flag toggling





Propulsion System Overview





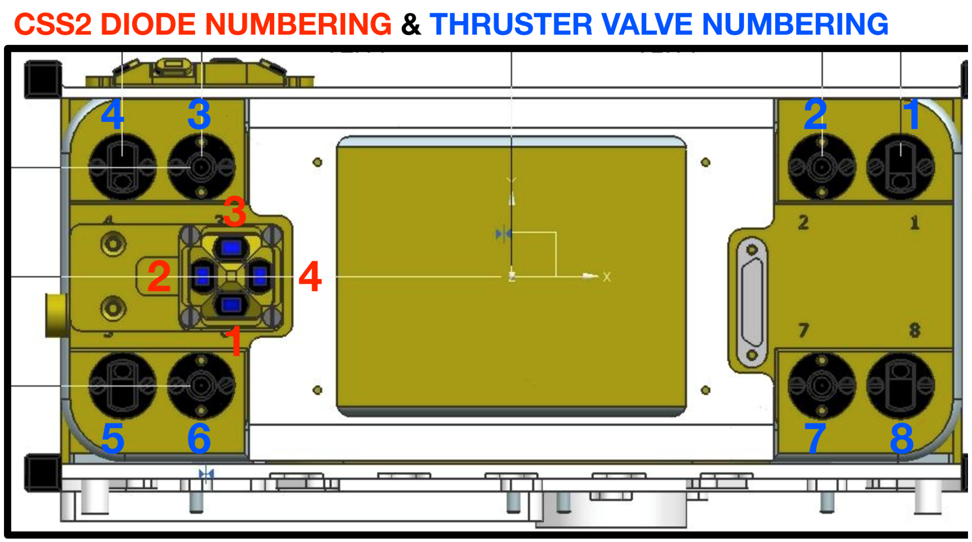
Propellant Mass Budget

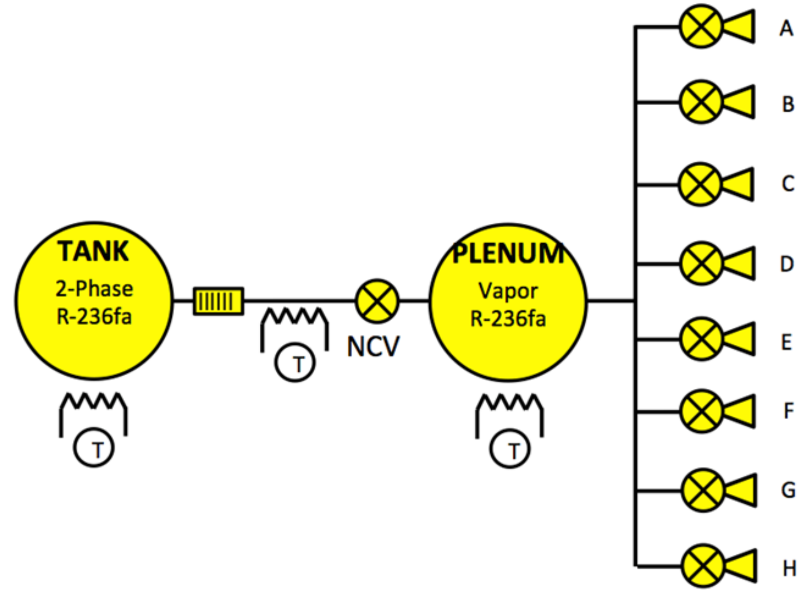
Disturbance Torques	Propellant Mass [g]
Momentum Management	150
Detumbling	50
Reaction Control Margin	100
Reaction Control Total	300
Delta-V Propellant Need	1200
Delta-V Margin	370
Unusable Propellant	30
Total Propellant	1900

Delta V Budget [m/s]

	TCM1	TCM2	TCM3	TCM4	TCM5	Total
Worst-Case Estimate	22.70	8.40	2.40	0.42	0.11	
					Sum	34.03
					Systems Margin	5.97
					Total Capacity	40.00

TCM and RCS Thrusters





- TCM thrusters are inner four thrusters (2, 3, 6, 7) provide axial force through off-pulsing
- RCS thrusters are used to correct for attitude excursions during DeltaV-mode firings
- DeltaV maneuvers require actuating the both tank/plenum valve and thruster valves
- DeltaV command requires both a total burn time across all thrusters and a wall-clock bound for the firings – duty cycle value informs the bound so that the specified accumulated burn time is reached before the cutoff

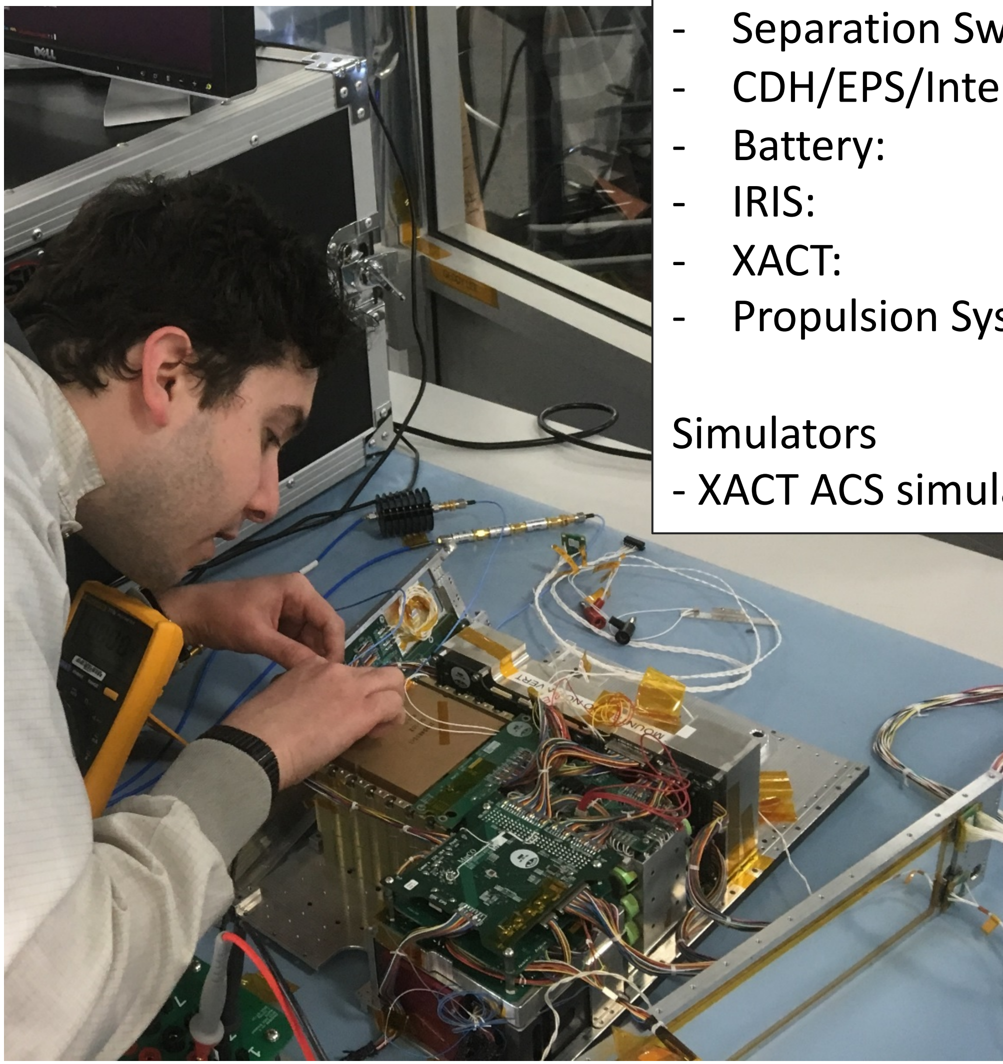
MarCO Ground Testbed

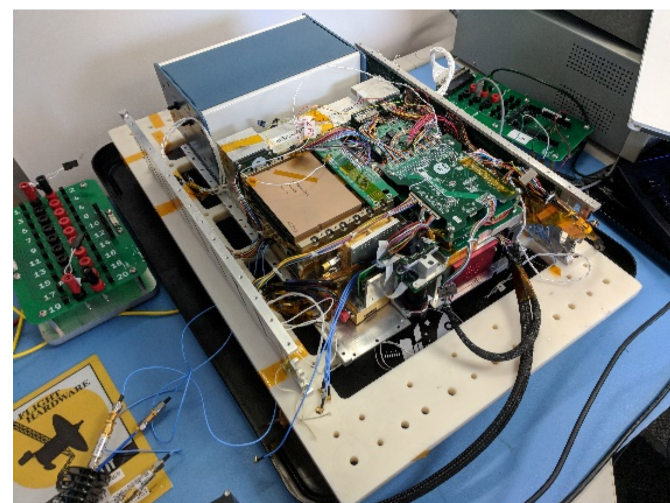
Comparison to FM:

- Separation Switch circuit	like FM
- CDH/EPS/Interface Boards:	like FM
- Battery:	like FM
- IRIS:	like FM1
- XACT:	like FM, but 1 CSS
- Propulsion System	electronics only

Simulators

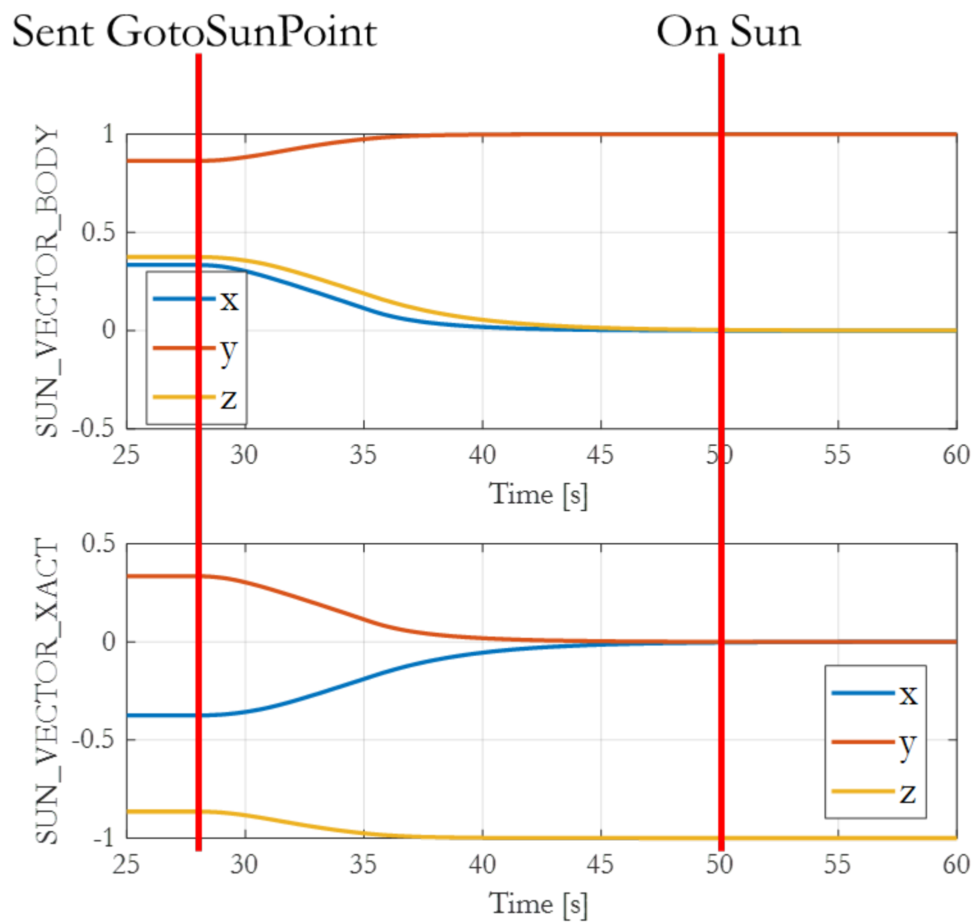
- XACT ACS simulator- Realtime Dynamics Processor (“RDP”)





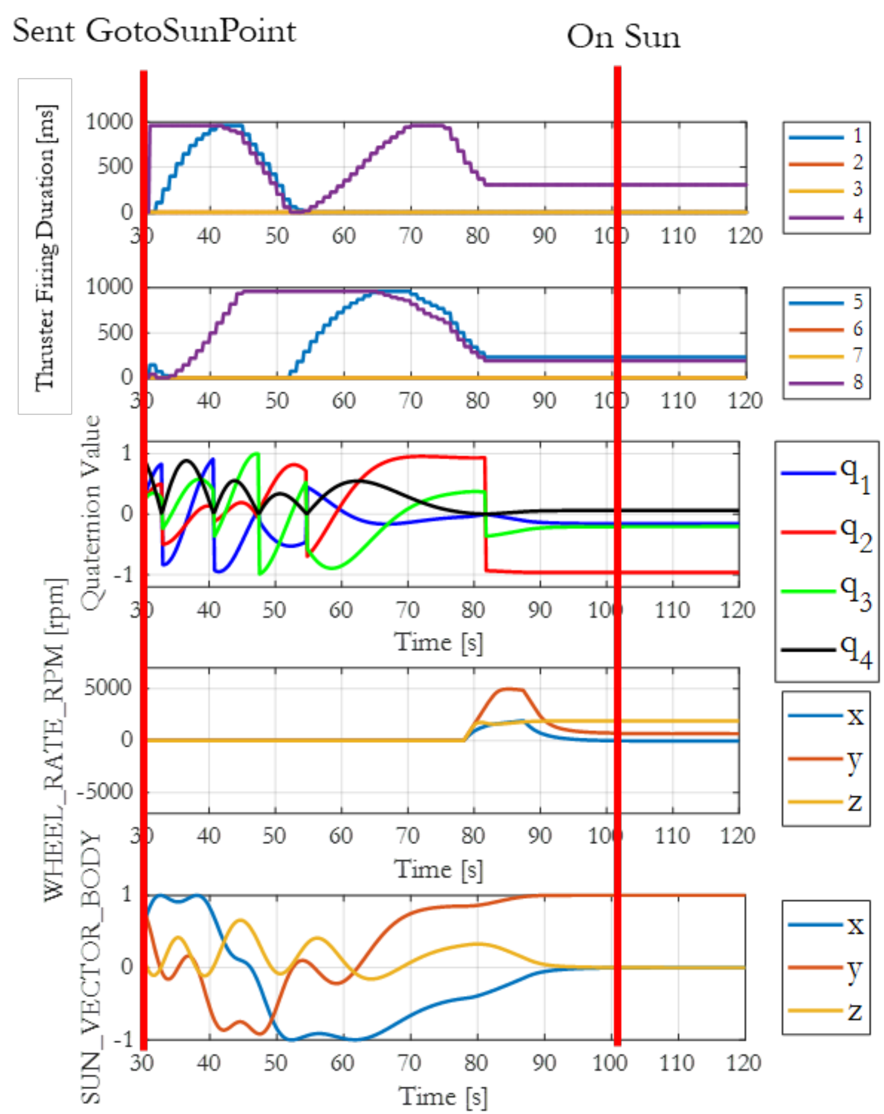
Ground Testbed Test: Sun Pointing

- Key safe mode functionality for ACS is to point the spacecraft to the sun to remain power positive
- RDP simulates the inputs to the sun sensors; SRU active but not included in estimator
- Base case: static spacecraft that must point to the sun
- Reaction wheels rotate the spacecraft to be stably sun-pointed within one minute of the command
- System momentum remained unchanged during the maneuver



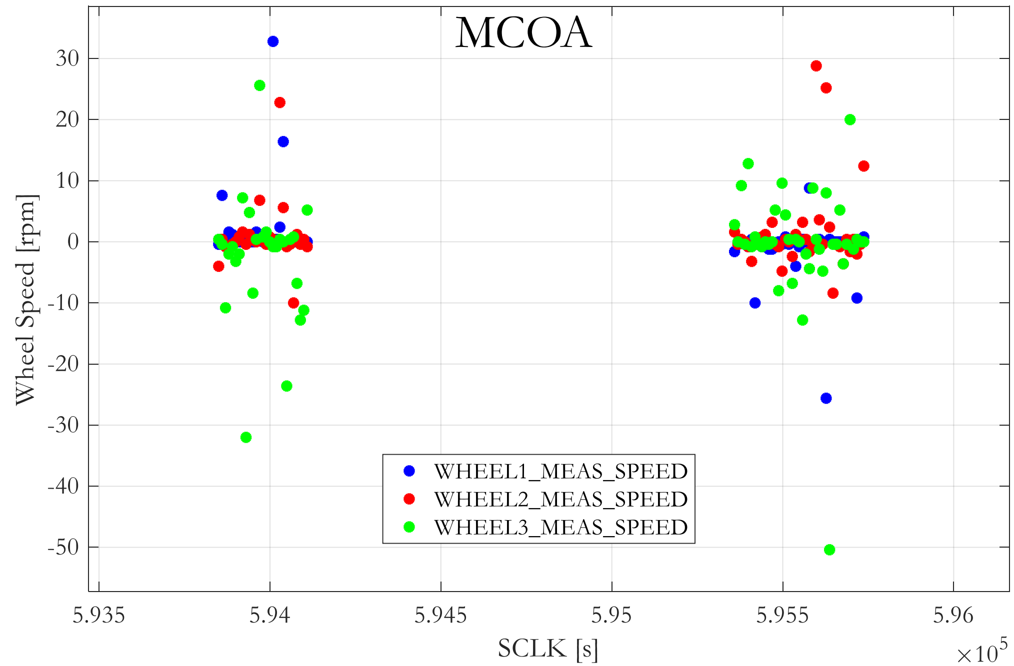
Ground Testbed Test: Tipoff Control

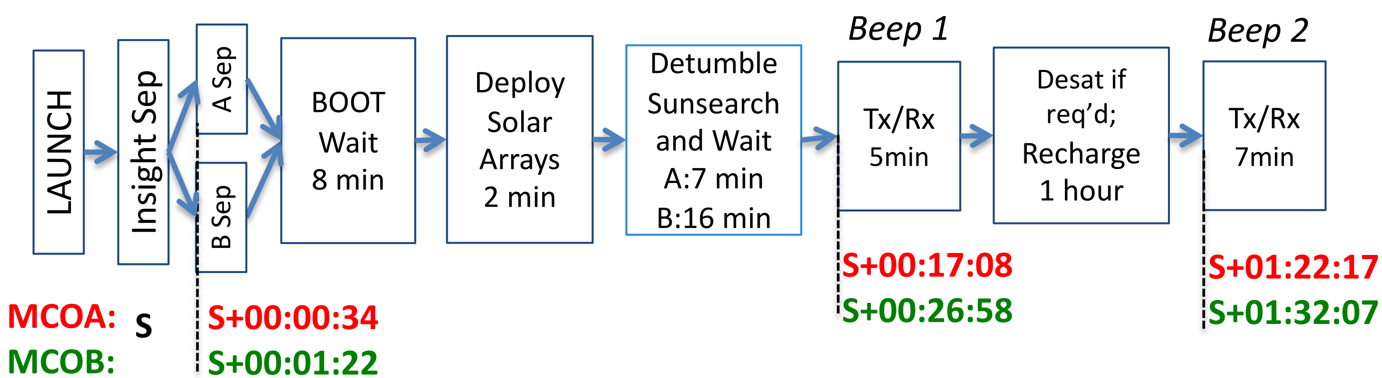
- More challenging sun point scenario occurs after deployment when the spacecraft could be tumbling
- Expected <2 deg/s/axis tipoff rates, so tested robustness to 30 deg/s/axis
    - High rate above momentum storage capacity of reaction wheels
- Thrusters fire to reduce body rates/system momentum to level at which reaction wheels take over
    - Reaction wheels not powered during thruster firings
- Achieve stable sun pointing within two minutes of command
- Serves as basic mission scenario test



Flight Data: First Telemetry

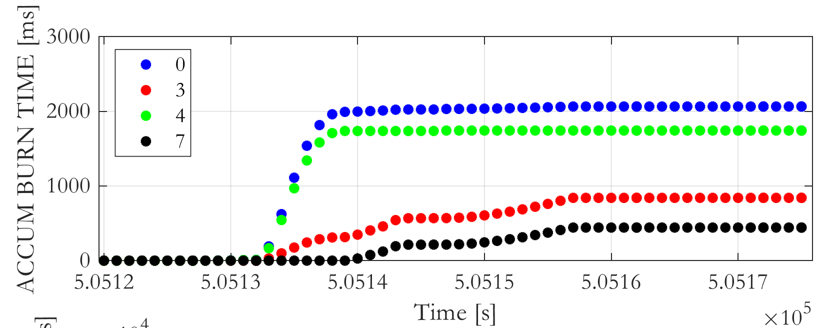
- First contact with the spacecraft was a pair of "beeps"
- Receive only (no commands sent) for five and seven minutes, respectively
- Each beep contained key telemetry to assess health of spacecraft
- Reaction wheel speeds indicate momentum stored after the desaturation if it was necessary and overall spacecraft attitude stability

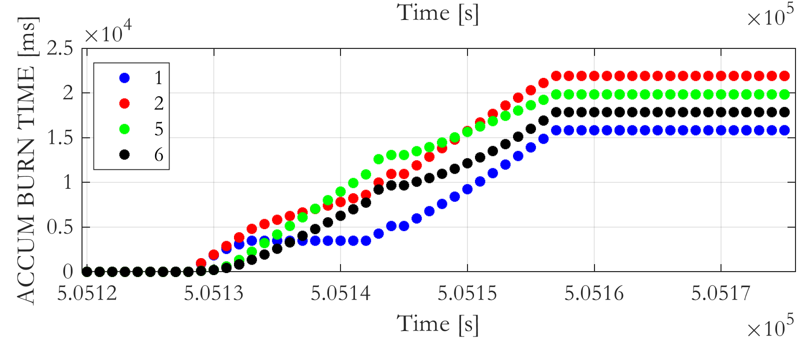


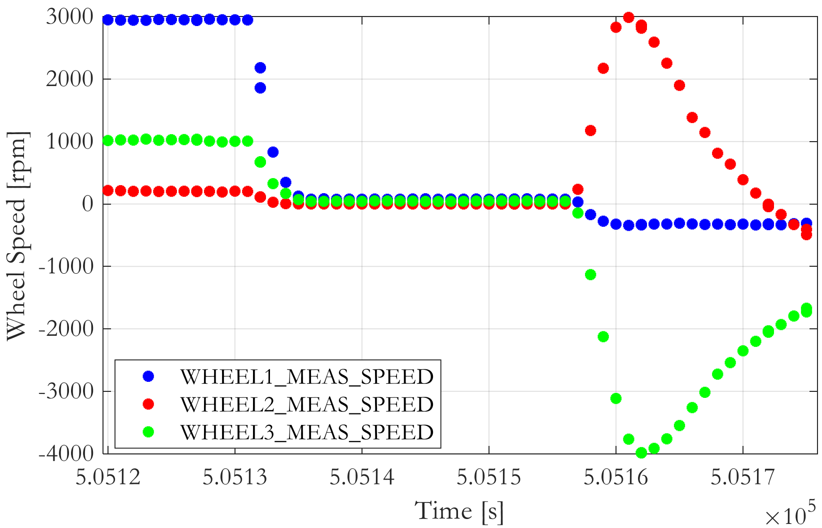


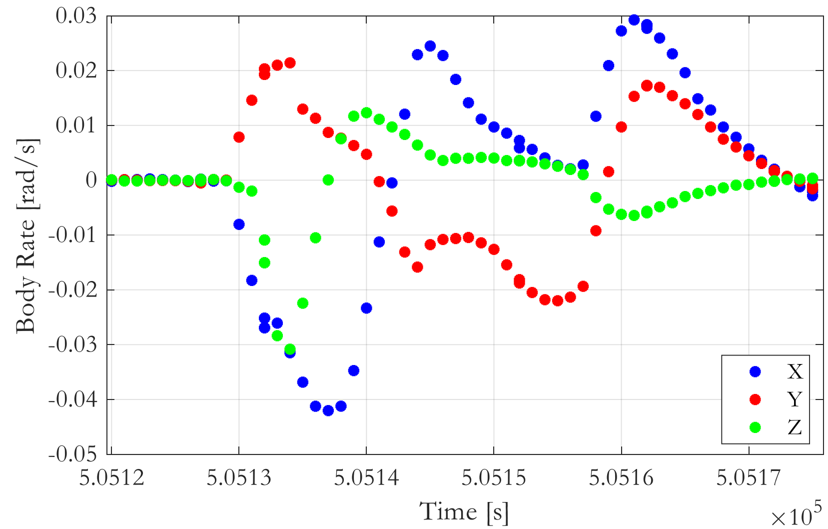
Flight Data: MCOA TCM2 Cleanup Maneuver

- TCMs performed in segments, with cleanup maneuvers for fine-tuning
- Off-pulsing thrusters is required for maintaining desired thrust direction
- Thruster controller is non-adaptive, so commanded thrust direction accounts for uncertainty in thrust levels and mass properties
- Spacecraft exhibits characteristic “nod” at start of burn, eventually corrected by reaction wheels at end of firing



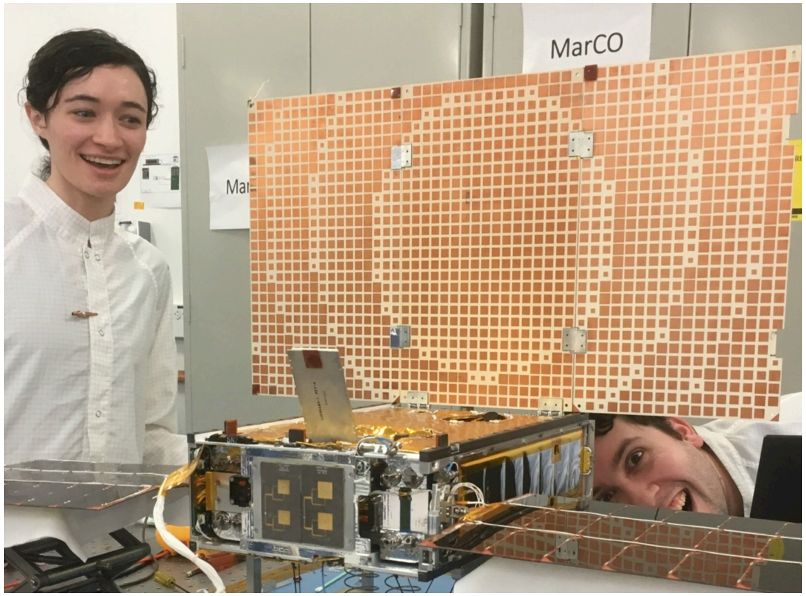






Key Lessons Learned

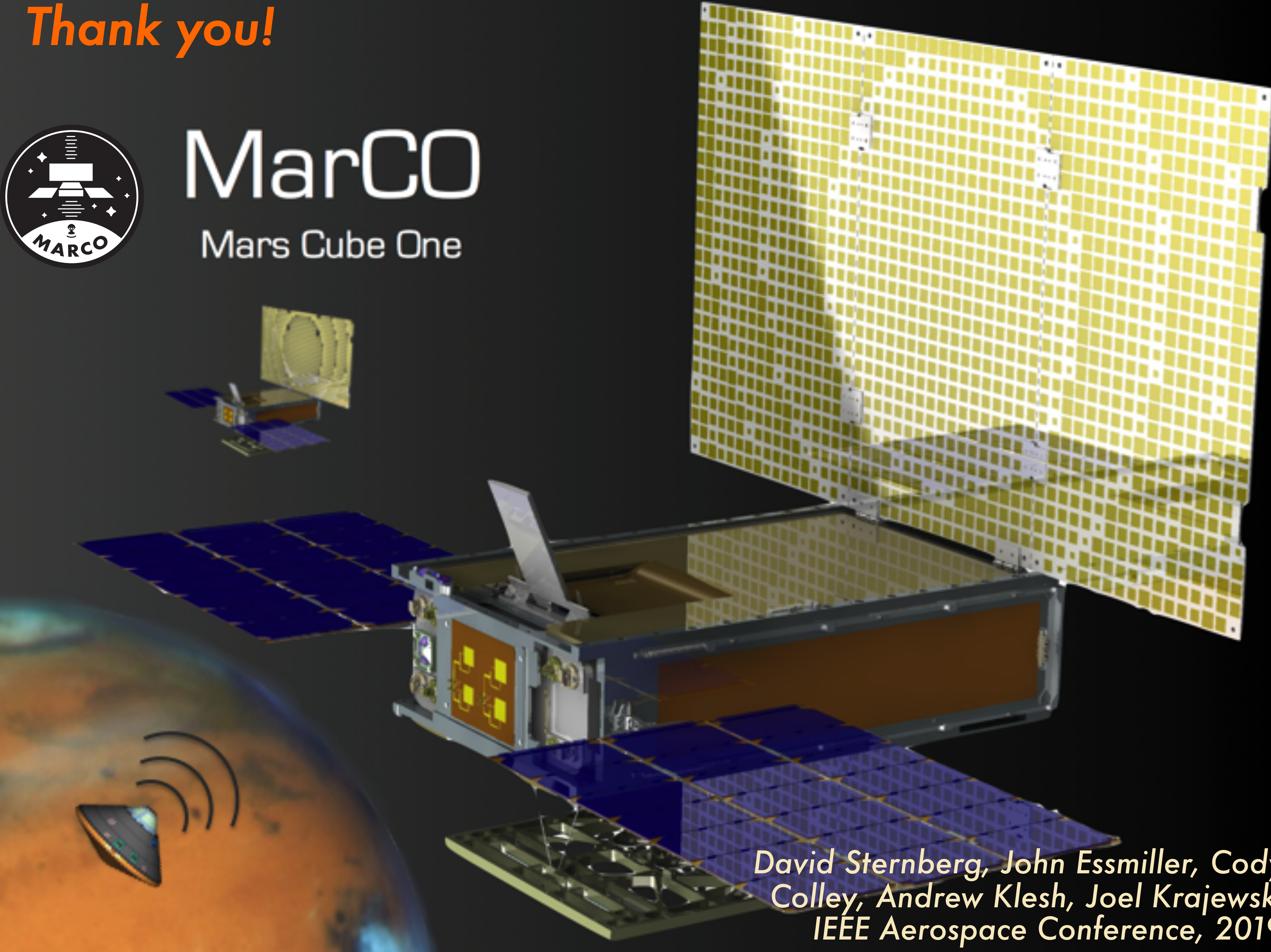
- Autonomous reaction wheel desaturations and directly commanded firings do not increment thruster accumulated burn times
- 2-phase propellant cannot use tank pressure as a metric for remaining fuel load
- TCM commands must account for controller accuracy to achieve desired pointing
- SRU can lose tracking lock from high rate slews and initial slew transients, which can lead to premature TCM cutoffs
- Parameterized fault protection values enable in-flight adjustments to tune spacecraft behaviors



Thank you!

MarCO

Mars Cube One



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